~~CONFIDENTIAL~~
[redacted]
A[redacted]ergy Act - 1

33

MASTER

Astronuclear
WANL-TME-536
SEPT. 1963

SUBMITTED BY:

Westinghouse Electric Corporation
Astronuclear Laboratory
Pittsburgh 36, Pennsylvania

~~INFORMATION CATEGORY~~
~~CRD~~
~~K F R~~ ~~9/30/63~~
~~Authorized Classifier Date~~

SPECIAL REREVIEW
FINAL
DETERMINATION
Class: U
Reviewers KAW Class. U Date 5/13/82

Classification cancelled (or changed to ___)
by authority of H.T.C. TIC, date SEP 11 1973
by ___

PREPARED BY:

R.B. Phillips

R.B. Phillips

A.I. Miller

A.I. Miller

APPROVED BY:

F.D. Retallick

F.D. Retallick

STATUS REPORT ON THE DESIGN SIGNIFICANCE OF COMPONENT TESTS

(Title Unclassified)

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

~~GROUP - 1~~
~~EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION~~

[redacted]FIDENTIAL
R[redacted]A
[redacted] 1954

DISCLAIMER

ABSTRACT

This report discusses the significance with respect to the NRX-A reactor design of flow tests on fuel element orifices, the tie rod liner, a misaligned fuel element and support block, a lateral support seal at low pressure isothermal conditions, fuel element channels at simulated full power operating conditions, and control drum drive shaft impedance paths.

TABLE OF CONTENTS

LIST OF FIGURES

[redacted]ergy Act - 1954

Astronuclear
WANL-TME-536

DESIGN SIGNIFICANCE OF COMPONENT TESTS

1.0 INTRODUCTION

This report is the second in a series of reports, the purposes of which are to outline the design significance with respect to the NRX-A reactor design of thermal and fluid flow results of the Component Test Program prescribed in WANL-TNR-095[(1)*]. The first report, WANL-TME-398[(2)], June, 1963, discussed results of the Tie Rod Hangar, Bushing, and Cone Support Flow Tests, Beryllium Reflector Assembly Air Flow Tests, Fuel Element Orifice Flow Tests, and Preliminary Support Block Flow Tests. The present report covers results of the Tie Rod Liner Flow Tests, Fuel Element Orifice Flow Tests, Fuel Element-Support Block Misalignment Verification Tests, Fuel Element Transpiration Leakage Tests, Fuel Element Flow Tests (used to evaluate pressure losses and heat transfer coefficients), Low Pressure, Isothermal, Lateral Support Seal Tests, and Control Drum Drive Shaft Loss Coefficient Tests. As additional test results become available, they will be included in Supplemental Design Reports.

Testing has been completed on the determination of the loss coefficient for the inner reflector-outer reflector impedance ring with air flowing through the model. In addition, some hydrogen flow testing of the beryllium reflector assembly has also been completed. However, data reduction was not completed in time for the results to be analyzed and included in this report.

---

* Numbers in parentheses refer to items listed in the Bibliography.

[redacted]

2.0 CONCLUSIONS

A. Transpiration Leakage From Fuel Elements

Initial test results indicate that the magnitude of the transpiration leakage flow in elements is negligible when compared to the core through flow. Its effect on flow, and ultimately on the core pressure distribution in the interstitial voids, may not be negligible. Tests are continuing to investigate other conditions and configurations.

B. Fuel Element Flow Test Results as Applied to the Determination of Pressure Loss and Heat Transfer Coefficients

Comparison of measured and calculated pressure losses shows reasonable agreement with the average value, obtained from about one hundred test runs, within 4% of the calculated value. However, considerable scatter exists in the measured data with some points differing by as much as 300% from the calculated values. Heat transfer coefficients (obtained from element surface temperature measurements) appear to be about one-quarter of those calculated by the empirical correlation shown in Section 3.4. Experimental work and data analysis are continuing in this area in an attempt to explain these discrepancies.

C. Low Pressure, Isothermal, Lateral Support Seal Test

When the seal is seated comparatively little flow leaks past the seat. As the filler strip gap increases, the flow rates passing through the gaps increase. The seal configuration acts like a flow restriction whose performance can be characterized by a loss coefficient, CL, which is a function of the Reynolds Number, N_{Re}.

D. <u>Control Drum Drive Shaft Loss Coefficients Test</u>

Preliminary data on the inlet loss coefficient for the four central control drum holes indicates a value of 2.07. Based upon these preliminary values, as compared to a calculated value of 3.79, the calculated value of CL used in the reflector system flow balance is high. However, the tests were performed without flow inthe outer eight holes of the drum and without a spring in the plenum chamber at one end of the drums. Testing and evaluation is continuing to include these effects in the test.

Preliminary results on loss coefficient values for the four, 0.25 inch diameter, control drive shaft holes indicate a loss coefficient of 1.40 as compared to a calculated value of 2.50. Again, the preliminary experimental loss coefficient is lower than the calculated value used in the reflector flow balance. Upon reevaluation of the calculated values, the measured value appears to be more in line with the area ratios and flow velocities involved. It is believed the velocity in the drive shaft is sufficiently low that the 0.25 inch diameter holes act more as an orifice rather than as a combination of turning flow and orifice. However, the value will be checked on subsequent tests with full flow and leakage through the drive shaft spline couplings.

E. <u>Fuel Element Orifice Loss Coefficient Tests</u>

The loss coefficients for the twelve sizes of production fuel element orifices have been determined over the ranges of Reynolds Numbers occurring at the full power operating condition. These experimental values of loss coefficients have been input to the "Orifice Selection Computer Program" to select the proper orifice for each fueled channel in the core to meet the design criterion of a maximum exit gas temperature variation of $\pm$ 200 $^{\circ}$R.

F. Fuel Element - Support Block Misalignment Verification Test

Ambient air tests agree very well with the analytical predictions for two tested conditions of misalignment.

G. Tie Rod Liner Tests

A modified Koo equation ($f = 0.00247 + 0.125\ N_{Re}^{-0.32}$) can be used to predict the pressure drop for the helically grooved stainless steel tie rod liner.

3.0 TEST RESULTS AND THEIR DESIGN SIGNIFICANCE

3.1 Fuel Element Orifice Loss Coefficient Tests (Test Specification A-8 of WANL-TNR-095)[1]

Hydrogen flow through the core is controlled by fuel element orifices in each individual channel. Ideally, flow is matched to local power factor by selecting an orifice of the proper loss coefficient so that a uniform outlet temperature is maintained. The loss coefficients necessary to accomplish this are specified by the "Orifice Selection Computer Program." In practice, however, only a finite number of orifice sizes can be specified, each with an allowable manufacturing tolerance. This results in an exhaust gas temperature variation across the core exit. The selection of orifice sizes is governed by the criterion of an allowable variation of $\pm$ 200 ^{o}R in exhaust gas temperature[6]. An additional tolerance of $\pm$ 50 ^{o}R is allowed on production orifices to account for manufacturing variations.

In order to select the orifices to meet the above criterion, twelve production fuel element orifices, of the type shown in Figure 3-1, ranging in diameter from 0.0225 inches to 0.070 inches were tested with ambient and cryogenic hydrogen at inlet pressures of 334 psia and 674 psia and covering the expected ranges of orifice Reynolds Numbers.

The tests and their results are presented, in detail, in WANL-TME-472[3]. The prinicpal result of these tests, as far as significance to the NRX-A design, is a plot of orifice loss coefficient versus orifice diameter at design operating Reynolds Numbers as shown in Figure 3-2. The data for this curve were obtained from the experimental plots of loss coefficient versus Reynolds Number for each orifice size tested. The loss coefficient was selected for each orifice size to conform to the range of orifice Reynolds Numbers (1.8×10^5 to 4.0×10^5) expected under full power operating conditions.

As seen from the figure, the loss coefficient reaches a minimum at a diameter of about 60 mils. Generally, one would expect the orifice coefficient to increase monotonically as the orifice hole diameter is decreased. However, if the physical configuration of the flow system is considered, the unexpected shape of the curve may be explained. As the orifice hole size is decreased from values above 60 mils, it approaches a size which equals the area of the vena contracta caused by the leading edge of the hole in the cluster plate. At this diameter, the fluid experiences no further losses, neither expansion nor contraction in passing from the cluster plate leading edge to the orifice. Below this diameter, the fluid must experience a further area contraction, above this diameter, a continuance of the expansion occurs beyond the vena contracta. Both of these result in the increased losses indicated by the data of Figure 3-2.

The loss coefficient required for each channel of each element is specified by the "Orifice Selection Computer Program." The program then combines these with the experimental data of Figure 3-2 along with the criterion for a variation in exhaust gas temperature of $\pm$ 200 $^{\circ}$R at full power operating conditions to select a particular orifice size for that channel. The production flow test acceptance limits result in an additional maximum variation in exit gas temperature of $\pm$ 50 $^{\circ}$R at full power operating conditions.

3.2 Fuel Element – Support Block Misalignment Verification Test

The alignment of the flow holes in the fuel element and the bottom support block is maintained by the compressive loading of the elements between supports and the lateral core bundling forces. Thus, misalignment between the coolant holes in the fuel element and the bottom support block can occur, thereby increasing the flow impedance. The decreased flow rate due to this increase in impedance results in a higher temperature channel. This is one of the many factors which is input to the "Hot Channel Analysis" in order to determine the statistical distribution of channel temperatures[7].

An analysis of the problem, using the MCAP[redacted] or SCAP[4] computer programs was performed. The test was devised to verify the analytical results under ambient flow conditions.

The analytical flow model treats the misalignment as a sudden area contraction and expansion at the point of transition from the fuel element exit to the support block entrance, occurring along the same channel center line. The results of the analysis are in terms of reduced channel flow rates for various amounts of misalignment. These reduced flow rates can be interpreted as resulting from a decrease in the effective channel diameter.

Verification tests were performed using ambient air but at Reynolds Numbers comparable to the full power operating condition. Data was obtained for two conditions of misalignment – 0.033 inches and 0.058 inches, overhang; i.e., the support block protrusion into the flow channel from its outer radius along a radial line. These results showed that in the aligned positions the effective channel diameter was 0.098 inches. At misaligned conditions, effective channel diameters of 0.0976 inches and 0.0937 inches were obtained for overhangs of 0.033 inches and 0.058 inches, respectively.

The theoretical analysis, for the same test conditions, showed effective channel diameters of 0.09685 inches and 0.09375 inches, respectively. Thus, the analysis is in close agreement with test results, at least under ambient conditions with no heat addition. This gives a reasonably high level of confidence in the use of the analytical methods to show the effects of misalignment on channel performance. Tests at high temperatures with heat addition will be performed to further corroborate the analytical methods.

3.3 Transpiration Leakage From Fuel Elements

A high leakage rate of hydrogen through the porous graphite of the fuel elements could affect core performance. Unfueled, uncoated elements for a cold flow core are expected to be more porous than the fueled, coated elements.

A test to measure the transpiration leakage of an uncoated, unfueled, Y-12 element has been made. A 6-inch length of an element was plugged at the exit and the internal flow passages were pressurized with hydrogen. After the system had been purged thoroughly, the flow rate was determined by measuring the rate of fall of pressure in a known volume attached to the element.

A plot of leakage rate as a function of pressure differential for this test is given in Figure 3-3. At a pressure differential of 30 psi, and an internal pressure of 45 psia the leakage rate is 0.42×10^{-7} lb/sec per inch of element. The effect of this leakage rate on the core temperature distribution would be negligible. However, the effect on the flow in the interelement void spaces may not be negligible since this flow rate is about the same order of magnitude as that calculated due to radial and axial inflow.

As indicated, these first tests were conducted with ambient temperature hydrogen discharging to the atmosphere. Furthermore, the supply volume, attached to the element, was small and transient effects could have been significant. Additional tests are presently being undertaken on other element types (fueled, coated) at design pressures to fully assess whether the magnitude of the transpiration leakage flow rates for actual reactor grade fuel elements is sufficient to significantly effect the core pressure distribution.

3.4 Fuel Element Flow Tests as Applied to Measurement of Pressure Loss and Heat Transfer Coefficients (Test Specification A2-3 of WANL-TNR-095)

The pressure loss and heat transfer coefficients used to predict core performance are based on empirical correlations of data which are not completely representative of core flow conditions. It is important, then, that these coefficients be measured at the temperatures and heat flux rates expected under full power operating conditions.

Flow and temperature data for fuel elements have been measured at various heat flux rates by heating fuel elements electrically. The primary purpose of these tests has been to measure the capability of fuel elements to resist corrosion by hydrogen at high material temperatures. In these tests, the hydrogen flow rate, inlet and outlet gas temperature and pressure, external element surface temperature, and electrical power are measured.

From these data, the average pressure loss and local heat transfer coefficient of the test may be determined. These values may then be compared to the coefficients predicted by the MCAP code using the standard design procedures.

The test average friction factor, calculated from the overall drop in total pressure and the average gas density, has been compared to the calculated average friction factor for about a hundred test runs. Two-thirds of the test points have been within 20% of predicted but the error range was $\pm$ 300%. The average friction factor of all the test runs was just 4% lower than the average of all the calculated values. The test data does not cover a wide flow or Reynolds Number range so it is not possible to show an error trend.

For the heat transfer comparisons, element surface temperatures were measured at four positions along the element. These measured temperatures have been compared to temperatures calculated in the MCAP and TOSS codes using flow and power conditions of the test. The film heat transfer coefficient used is calculated in the MCAP program according to the empirical relationship.

$$\frac{hD}{k} = .025\,(N_{Re})^{.8}\,(N_{Pr})^{.4}\,(Tw/Tg)^{-.55}\,\left(1 + .3\,(X/D)^{.7}\right) \qquad (3\text{-}1)$$

where

h	=	heat transfer coefficient
D	=	diameter of flow passage
k	=	thermal conductivity of gas
N_{Re}	=	Reynolds Number
N_{Pr}	=	Prandlt Number
Tw	=	temperature of heat transfer surface
Tg	=	coolant temperature
X	=	length from entrance to point of calculation.

Heat loss from the element by radiation is a large and unaccounted for effect in these initial measurements. Nevertheless, measured temperatures have been about 1000° hotter than calculated, as in Figure 3-4. The data have been remarkably consistent.

In order to get good correspondence between measured and calculated results, it would be necessary to use heat transfer coefficients of about one quarter of those given by the above equation. In view of the data represented by this equation, it seems quite unlikely that so large an effect can be explained by inaccuracy of the heat transfer coefficient. If heat loss from the element is considered, the correspondence between measured and calculated becomes even worse.

A logical explanation for the difference between measured and calculated results is a combination of an error in measured flow rate (or flow by-passing the element) and the neglected radiation loss from the element surface. An investigation is presently underway to explain the apparent disparity between test results and the analysis. The analytical procedure is being modified to account for radient heat loss.

3.5 Tie Rod Liner Friction Loss (Test Specification A-7 of WANL-TNR-095)

A metered flow of hydrogen is required to cool the tie rod and stainless steel liner. Pressure drop in the coolant path consists of the centering bushing loss, friction loss through the annulus between the tie rod and liner, and a loss through the support cone.

The loss coefficient for the centering bushing and for the support cone have been measured and reported in WANL-TME-398[2]. The frictional pressure loss in the tie rod annulus has been evaluated for the NRX-A reactor design in the tie rod computer program from the empirical Koo equation,

$$f = .0014 + .125 / N_{Re}^{.32} \qquad (3\text{-}2)$$

where f is defined by

$$\Delta P = (G_n)^2 / g\,(\Delta V) + f2\,(G_n)^2\,LV/gD_h\ . \qquad (3\text{-}3)$$

where

f	=	friction factor, dimensionless
ΔP	=	pressure drop, psi
G_n	=	mass flow rate, lbs/sec-in^2
g	=	gravitational constant, in/sec^2
V	=	specific volume, lbs/in^3
L	=	length, in.
D_h	=	hydraulic diameter, in.

This relationship is known to correlate friction pressure loss for smooth tubes. The present NRX-A design uses tie rod liners having a helical groove in the flow path as shown in Figure 3-5. This helix may alter the flow field so that the pressure drop can no longer be correlated by the smooth tube relationship, Equation 3-2. A test program was undertaken to measure the friction factor of the helical liner. The friction factor of a smooth liner was measured in the same test fixture as a control test.

The test fixture consisted of a model of the tie rod flow path of the core. Hydrogen flow passed from a plenum into the positioning spring chamber and then to the tie rod-liner annulus. After passing through the annulus, the flow discharged through the support cone into an exit plenum. The pressure loss was measured from the positioning spring chamber to a point just downstream of the liner but in front of the cone support.

The test conditions covered a flow range of 8 to 74 lbs/hr of hydrogen, inlet pressures of 584 psia and 270 psia, and temperatures of 250 $^{\circ}$R and 555 $^{\circ}$R.

Preliminary data have been reduced and analyzed. The friction factor was calculated for each test run using Equation 3-3. Figure 3-6 shows the comparison between the friction factors for helical and smooth tie rod liners. The Koo equation is also plotted to show that the degree of correlation for the smooth tube data is rather good. The data for the helical tie rod liner is found to be correlated by the equation

$$f = 0.00247 + \frac{0.125}{N_{Re}^{0.32}} \qquad (3\text{-}4)$$

3.6 <u>Low Pressure, Isothermal, Lateral Support Seal Tests (Test Specification B-3 of WANL-TNR-095)</u>

A model of the flow passages about a single seal was constructed and tested[(5)] with low pressure, ambient air. A schematic of the model is shown in Figure 3-7. The model consisted of a plexiglas container, a single graphite seal segment, graphite filler strips, and a simulated graphite inner reflector. The filler strip gaps, side clearances, and top clearances could all be varied independently.

Tests were performed on the model with ambient air at inlet pressures of 5-25 psig and flow rates up to 0.1 lb/sec.

Due to the design and method of construction of the model, it was found to be virtually impossible to seal the container either internally or externally so that air did not leak to the outside of the container or around internal components, short-circuiting the flow passages. In addition, each time a change in the internal configuration (e.g., an increase in filler strip gap) was required, the model had to be partially disassembled, thereby changing the nature and size of any leakage channels that existed during the previous test. Thus, the data obtained from this test has only been used in a qualitative fashion and no quantitative answers applicable to the NRX-A design have been obtained.

The qualitative application of the test results and their significance to the NRX-A design fall into three categories: seal seat leakage, the effect of filler strip gap, and characterization of the seal as flow restriction described by a loss coefficient as a function of Reynolds Number.

When the seal segment is seated against the inner reflector, comparatively little flow passes through the seal interface. This is shown by comparison of Figures 3-8 and 3-9. In Figure 3-8 the effect of top clearance on the flow around a centered seal segment with 0.010" side clearances is shown. In this test the filler strip gap was maintained at zero by use of a solid block and the top clearance was varied from 3/64" to 3/16". Although the scatter in the original data was considerable (due undoubtedly to the varying leakage), distinct and different loss coefficient levels (based upon 0.010" side clearance gap) resulted for each of the three top clearance values investigated, with the highest loss coefficients occurring with the minimum top clearance. These results indicate that a considerable portion of the flow did indeed pass through the 0.010" passages, and the effect of reducing the top clearance was to increase the frictional, contraction, and/or expansion losses in the intermediate flow passage over the top of the seal segment. When the seal segment is seated against the inner reflector, no significant effect of top clearance is observed. This is shown in Figure 3-9 where loss coefficient (based upon 0.020" side clearance gap) data for two tests, performed with the seal seated and only the top clearance varied, are plotted. Inspection of the data reveals no systematic variation between the two conditions. Although the data shown was for a configuration with a filler strip gap incorporated, similar results were also obtained with a solid block in place of the filler strips. Since top clearance effects were noted (Figure 3-8), when a major portion of the flow passed over the top of the seal segment, and no such effects can be seen when the seal is seated (Figure 3-9, it is reasonable to conclude that the magnitude of the seat leakage flow in the cases investigated, was very much smaller than the extraneous leakage which existed within the model. However, since it was not possible to determine the latter from these tests, no estimates of the seat leakage flow can be made at this time.

The effect of filler strip gap size is illustrated in Figure 3-10 where the loss coefficient (based upon the 0.020" side clearance) is seen to increase as the gap size decreases. Again, it should be emphasized that the numbers shown in the figure cannot be applied to the NRX-A design due to the uncertainty in the extraneous by-pass leakage rates and can only be used for this qualitative comparison.

Inspection of the test results for the centered seal (Figure 3-8) and those for the seated seal with or without filler strip gap (Figures 3-9 and 3-10) indicate that the flow description of the seal; i.e., as a resistance described by a loss coefficient as a function of Reynolds Number, as used in the NRX-A design analysis, is a valid one.

3.7 Control Drum Drive Shaft Loss Coefficient Test (Test Specification D4-1 of WANL-TNR-095)

3.7.1 Inlet Loss Coefficient

In the analysis of the flow distribution in the reflector system, the flow path in the control drum is divided into three parallel paths: the control cylinder holes (19 - 0.1875" diameter holes per cylinder); the control vane inner annulus; and the control vane outer annulus. The assumption has been made in the design analysis that each of the 19 control cylinder holes receives an equal portion of the total flow. The four (4) central holes are fed primarily by flow through the hub of the nozzle end bearing shaft, and the outer fifteen (15) holes arranged eight (8) and seven (7) on concentric circles, are fed by in-line holes in the flange of the nozzle end bearing shaft as shown in Figure 3-11. In addition, there is a variable radial ring clearance* between the face of the nozzle end bearing shaft and the nozzle end of the beryllium control cylinder through which the flow can redistribute itself between the four inner holes and the fifteen outer holes. Thus, the component tests on the control drum drive shaft and the full control drum have been designed to furnish data on the flow distribution in these cooling holes.

Preliminary data has been obtained for the loss coefficients for the 0.531" diameter hole in the hub of the nozzle end bearing shaft and for the entrance to the four central cylinder holes. The results, shown in Table 3-1 were obtained using ambient air for a configuration which had the outer cylinder holes sealed (i.e., no flow through the ring clearance) and had no spring in the plenum chamber.

As can be seen from the results, the loss coefficients decrease as the ring clearance increases. This may be due to changes in the plenum volume which occur when the ring clearance is varied.

Preliminary calculations have been performed to determine the inlet loss coefficient (for the four central holes) using the above data. These result in an inlet loss coefficient (based upon the control cylinder hole diameter) for the four central holes of 2.07. This is compared with a value of 3.79 originally calculated and used in the reflector

* This ring clearance has an assembled nominal value of 0.142". During power operation, this will decrease due to the differences in expansion between the beryllium control cylinder and the aluminum housing.

[redacted]

flow balance. Since the data is only preliminary in nature, in that it was obtained during calibration test runs and without the spring in place, final comparison between experimental and analytical results is awaiting tests now in progress on the design configuration. The results of these tests will be used to modify the reflector flow balance.

3.7.2 Exit Loss Coefficient

Preliminary data for the loss coefficient for the four (4), 0.25" diameter drive shaft holes have been obtained. In the original design analysis, these holes were considered as orifices following a 90° flow turn, and a loss coefficient of 2.5 was calculated. The preliminary data gives a loss coefficient of only 1.40.

Re-evaluation of the area ratios for these holes and the flow velocity within the drive shaft indicate that the pressure losses in this flow passage should be compared as only a sudden contraction loss and a sudden expansion loss. The turning loss is negligible due to the low velocities which exist within the drive shaft. A calculated loss coefficient for the sudden contraction is 0.29 (based upon an area ratio, orifice area/drive shaft area, of 0.34) and for the sudden expansion is 1.0. The combined loss coefficient is, therefore, calculated to be 1.29, agreeing well with the preliminary experimental result of 1.40. The experimental value of this loss coefficient will be checked on subsequent tests on the drive shaft test rig with full flow through all the flow passages and leakage through the coupling splines. The resulting loss coefficient will be incorporated into the reflector flow balance when experimental loss coefficients for the rest of the control drum flow passages, as well as the other reflector components become available.

BIBLIOGRAPHY

1. WANL-TNR-095, "NRX-A Component Test Program.

2. WANL-TME-398, "Design Significance of Component Tests," June, 1963, A. I. Miller.

3. WANL-TME-472, "Experimental Determination of Orifice Coefficients for Production Type Fuel Element Orifices for NRX-A1," August 5, 1963, H. J. Fix.

4. WANL-TNR-045, "A Single Channel Analysis Program (SCAP) for the Temperature Distribution in an Internally-Cooled Heat Generating Solid Cooled by a Compressible Gas, Feb., 1962, B. L. Pierce.

5 WANL-TME-532, "Single Seal, Low Pressure, Isothermal Test," September, 1963.

6. WANL-TNR-128, "NRX-A Design Report," September, 1963.

7. WANL-TME-539, "A Method of Statistical Analysis of the Effects of Manufacturing Assembly and Operating Deviations on Operating Temperatures of the NRX-A Core," September, 1963, D. Buskirk.

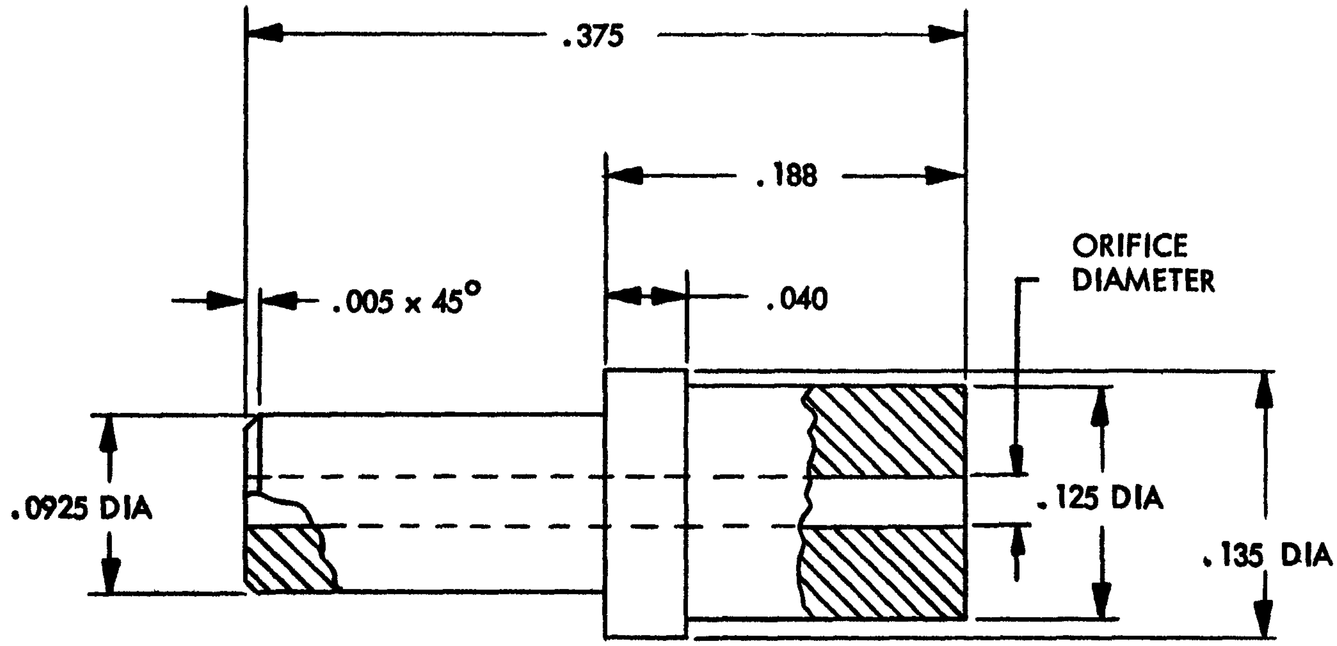


FIGURE 3-1 **Fuel Element Orifice**

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

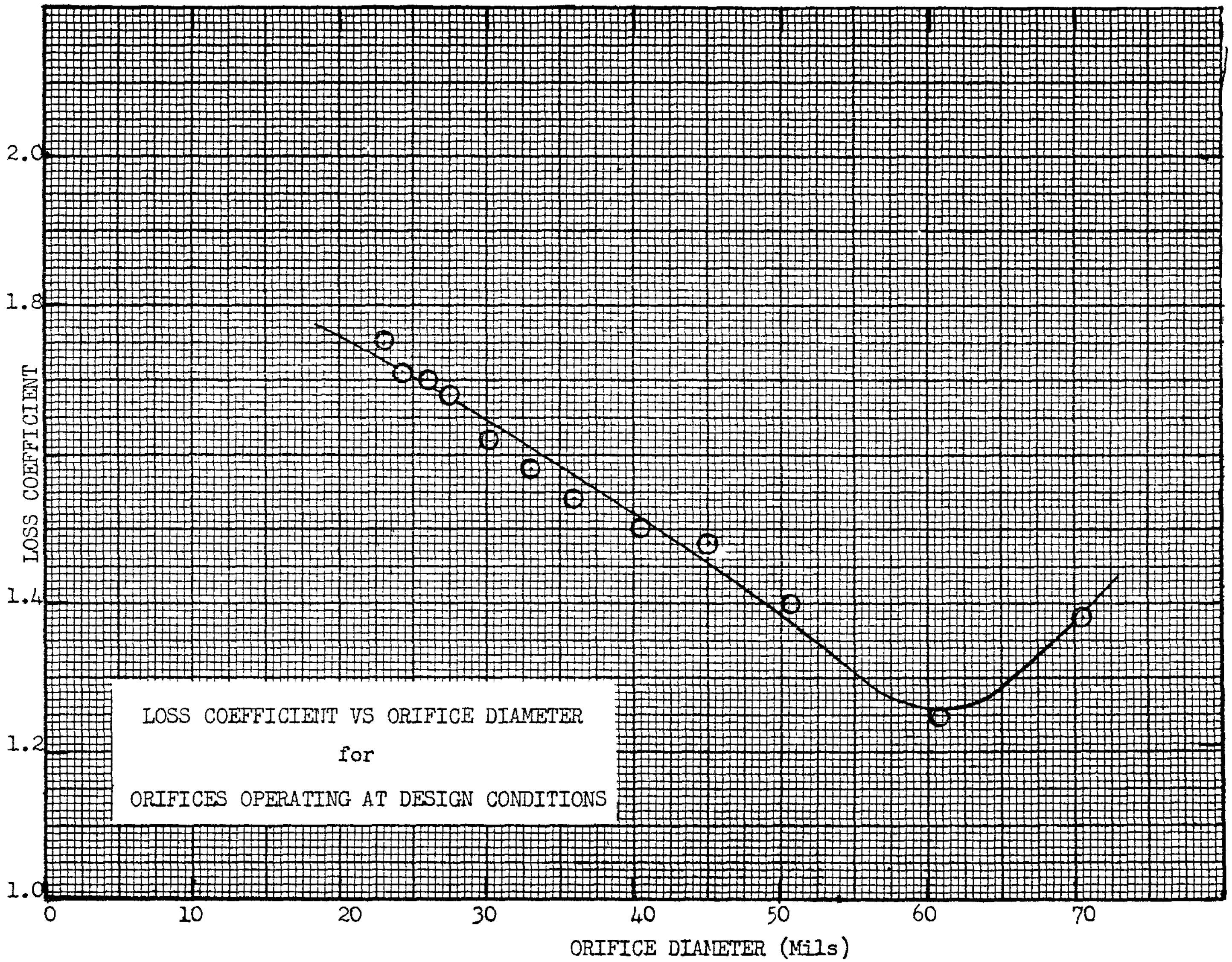


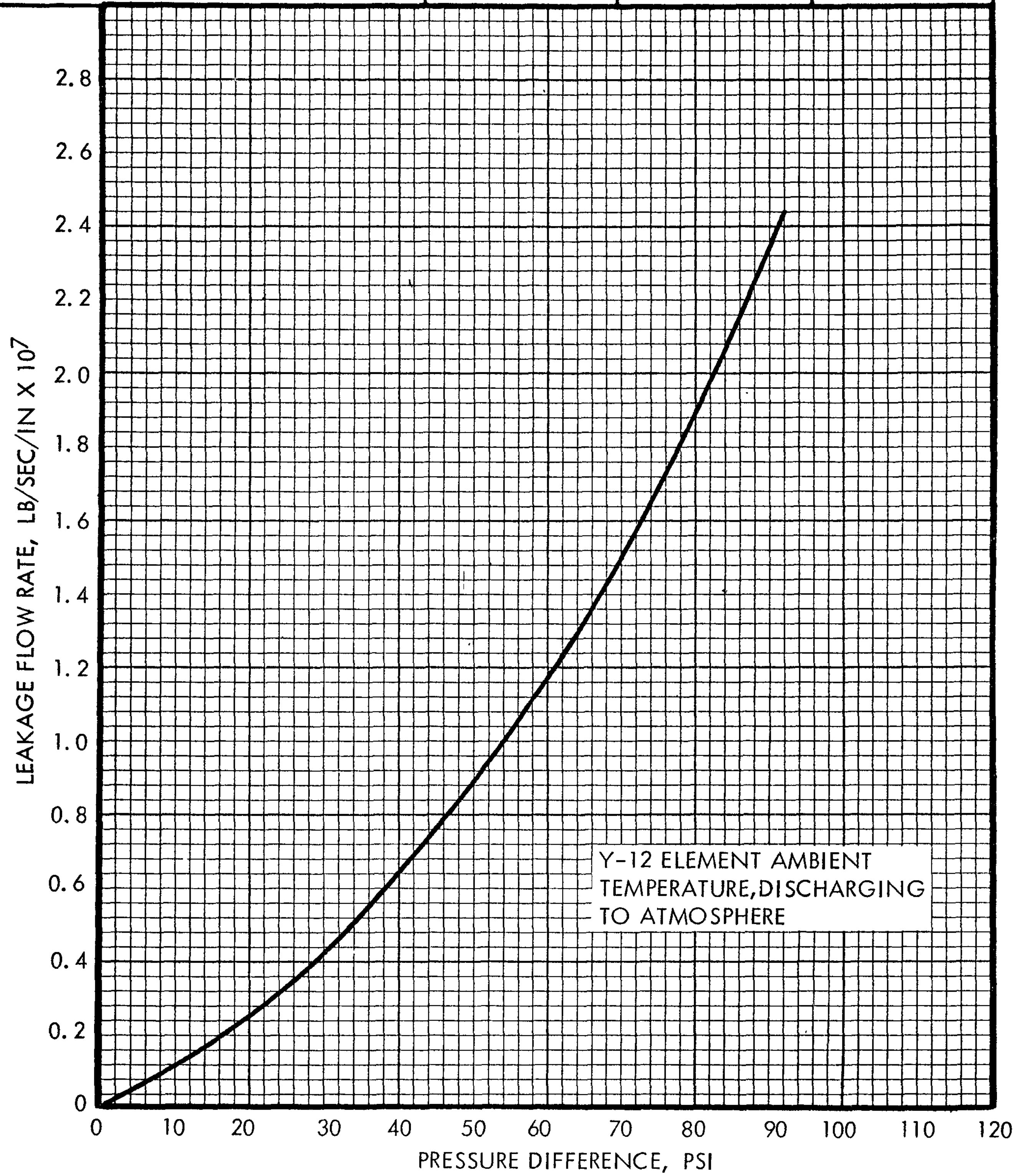
FIGURE 3-2 Loss Coefficient vs Orifice Diameter for Orifices Operating at Design Conditions

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
[redacted]

Astronuclear

~~CONFIDENTIAL RESTRICTED DATA~~ [redacted]

REFERENCE		PREPARED BY	APPROVED BY	Astronuclear

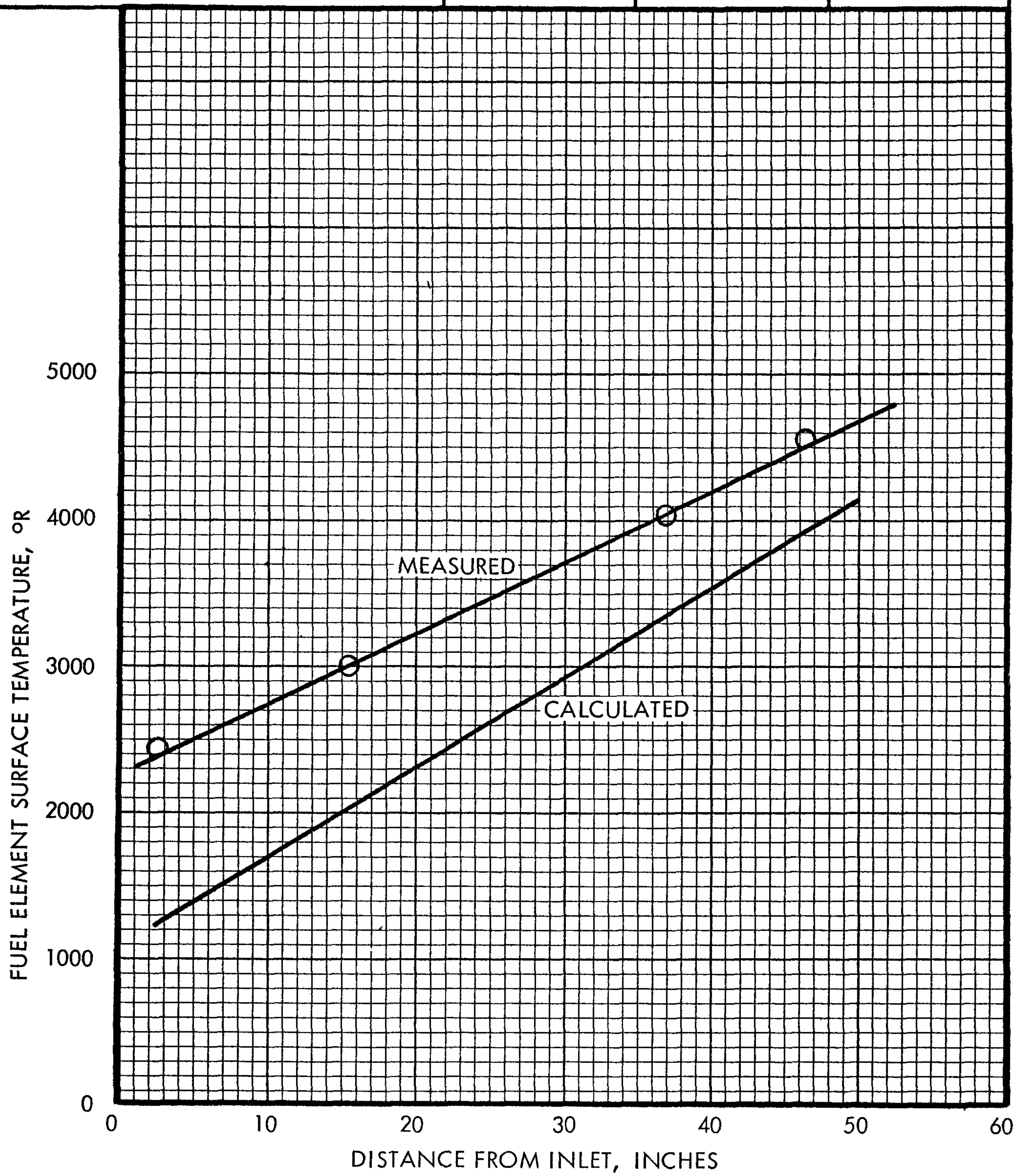


	CURVE NO.	FIGURE NO.
TRANSPIRATION LEAKAGE RATE	595579	3-3

~~CONFIDENTIAL RESTRICTED DATA Atomic Energy Act of 1954~~

~~CONFIDENTIAL RESTRICTED DATA Atomic Energy Act of 1954~~

REFERENCE		PREPARED BY	APPROVED BY	Astronuclear



COMPARISON BETWEEN MEASURED AND CALCULATED VALUES OF THE FUEL ELEMENT SURFACE TEMPERATURES	CURVE NO.	FIGURE NO
	595578	3-4

~~CONFIDENTIAL RESTRICTED DATA Atomic Energy Act of 1954~~

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

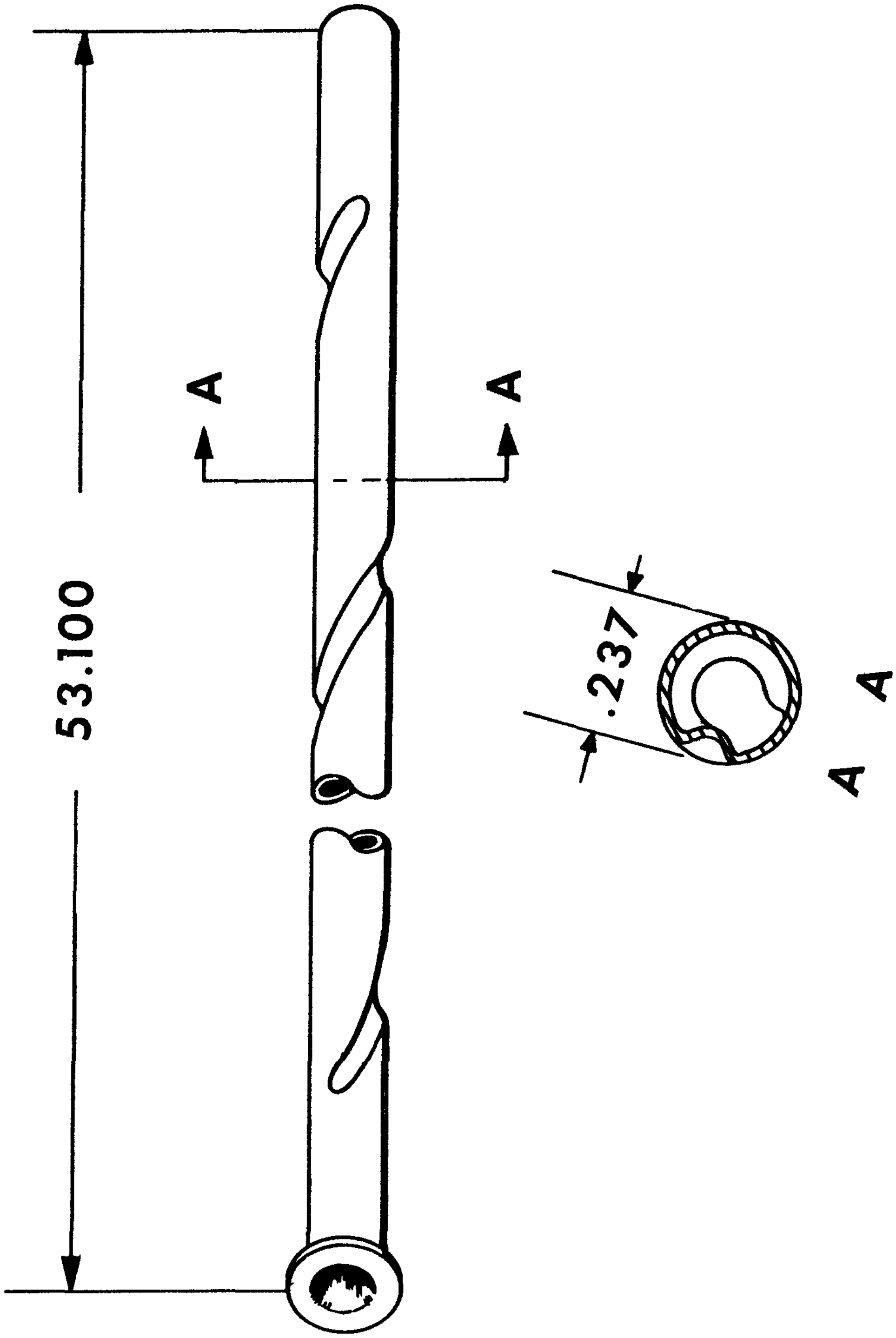
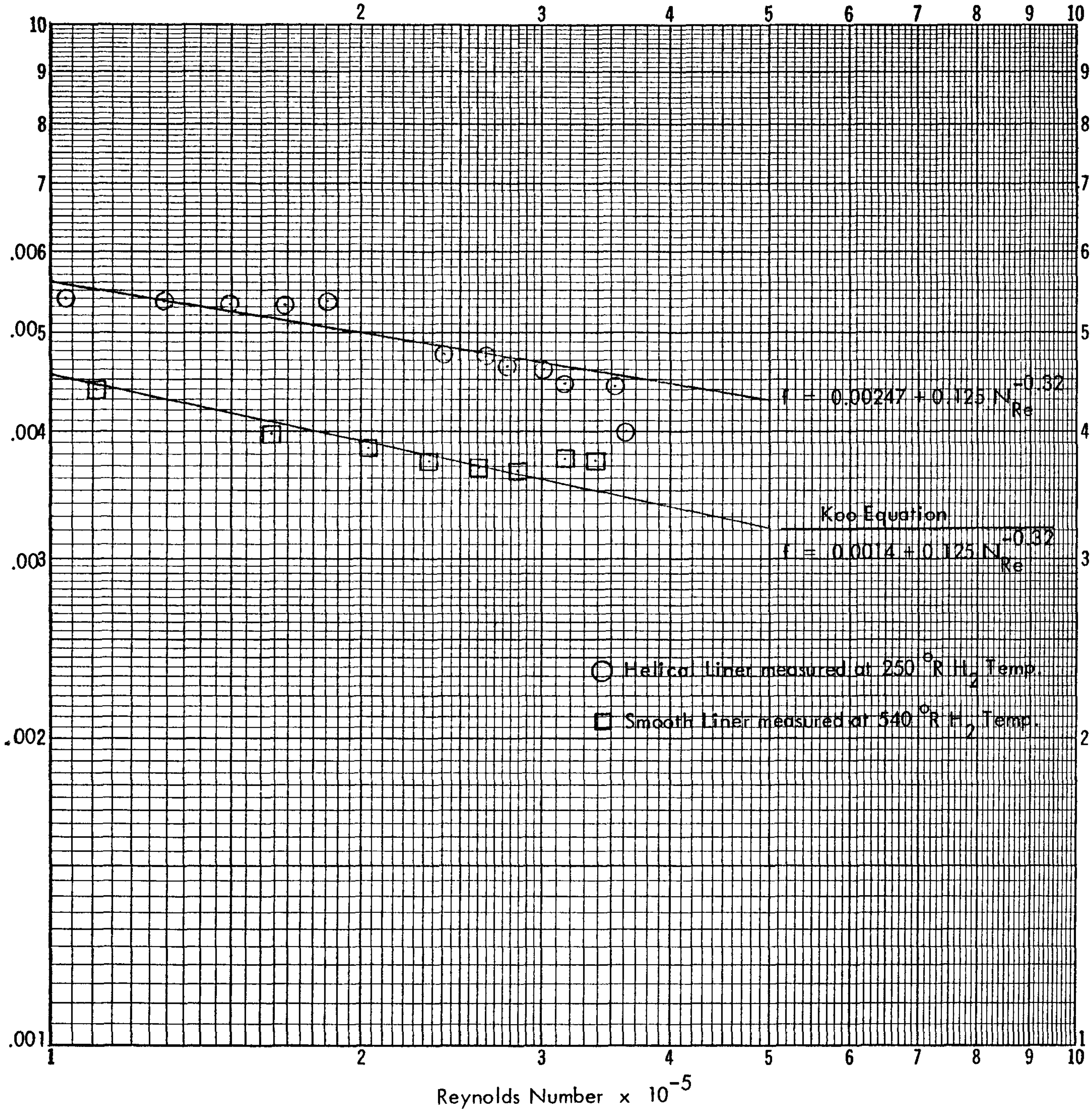


FIGURE 3-5 DRAWING OF HELICALLY GROOVED STAINLESS STEEL LINER

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act - 1954~~

[redacted]

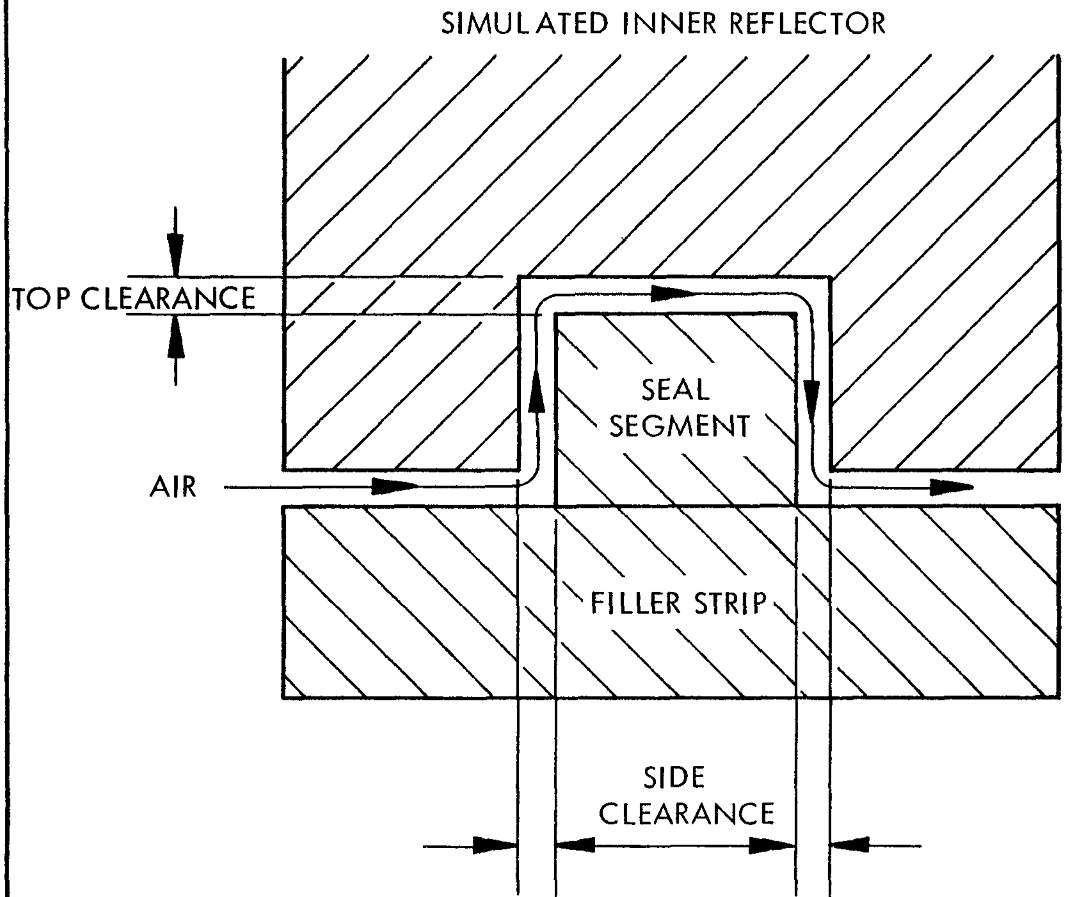


COMPARISON OF FRICTION FACTORS FOR HELICAL AND SMOOTH TIE ROD LINERS

FIGURE 3-6

[redacted]

REFERENCE		PREPARED BY	APPROVED BY	Ⓦ Astronuclear

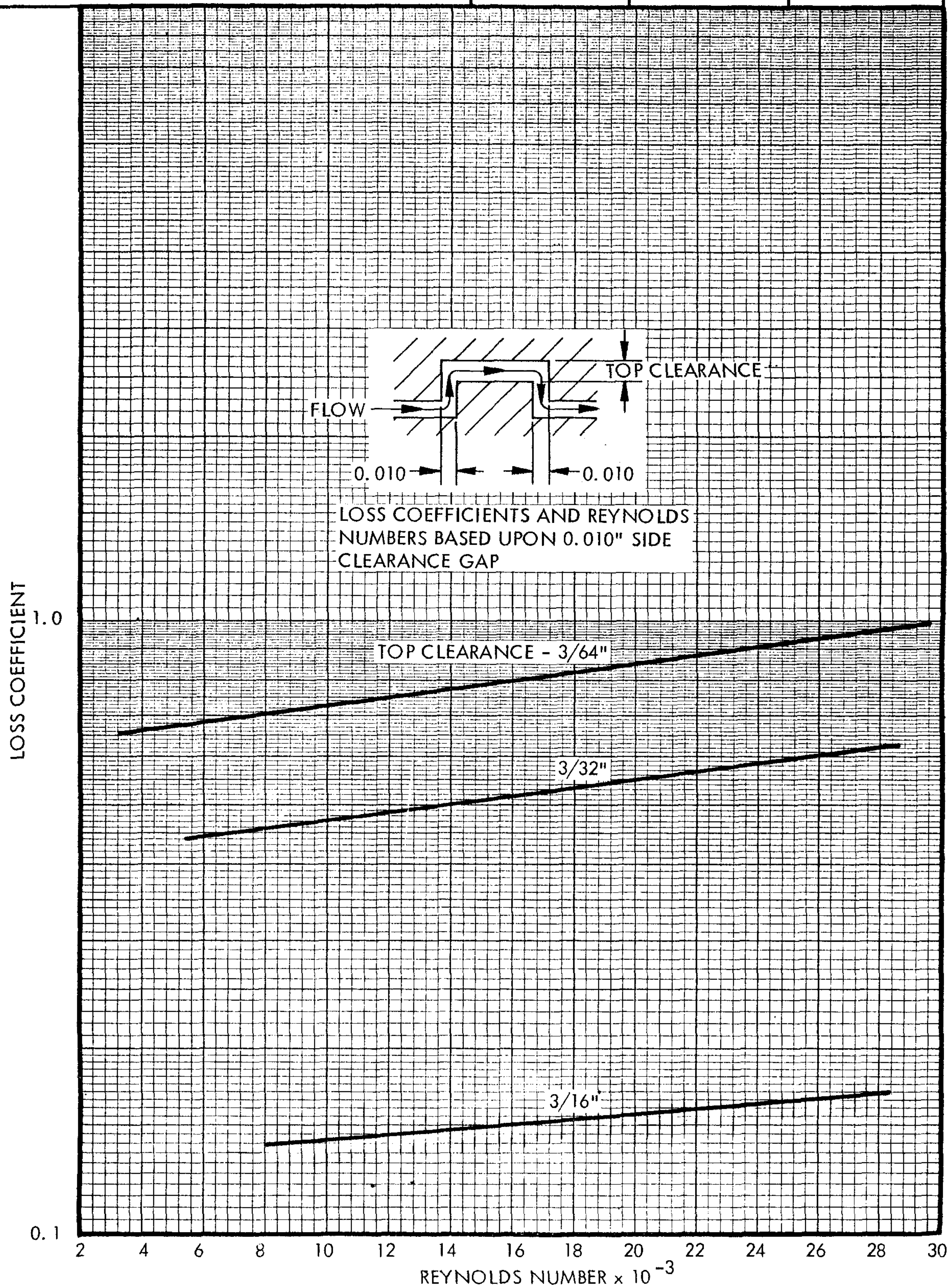


CURVE NO. 595577

SCHEMATIC OF LOW PRESSURE, SINGLE SEAL MODEL

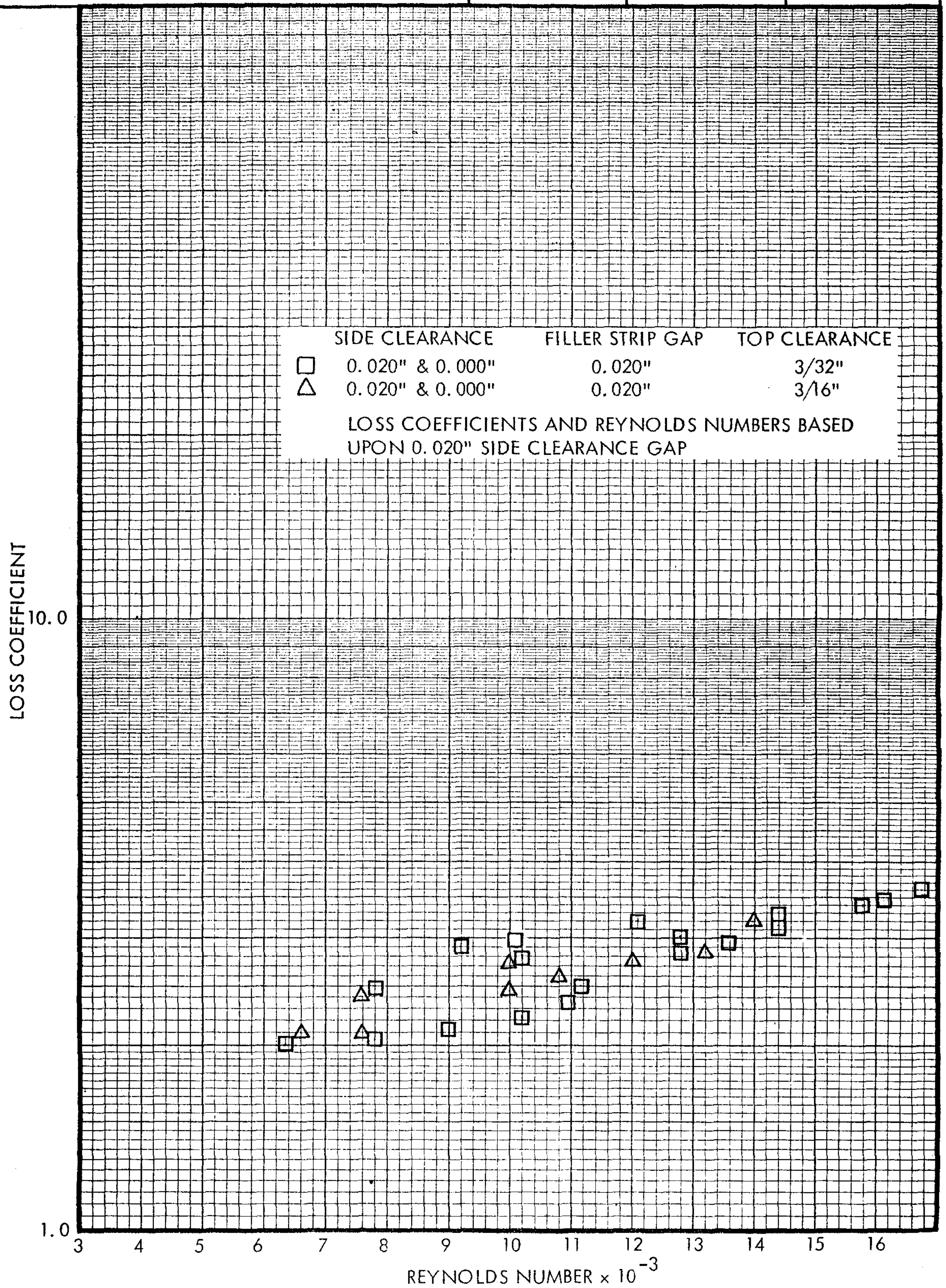
FIGURE NO. 3-7

REFERENCE		PREPARED BY	APPROVED BY	



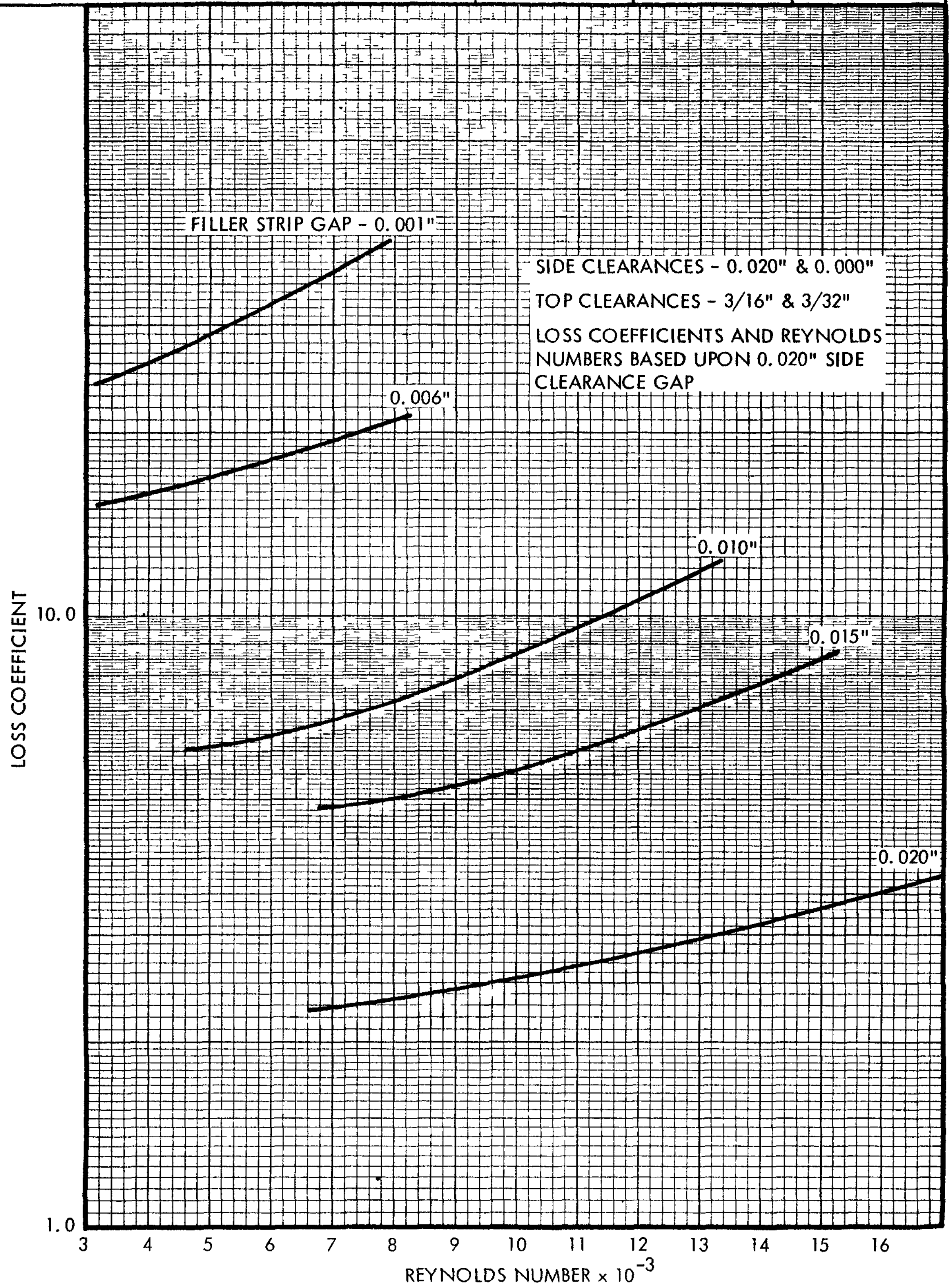
EFFECT OF TOP CLEARANCE ON FLOW THROUGH EQUAL 0. 010 INCH SIDE CLEARANCE GAPS	CURVE NO.	FIGURE NO.
	595583	3-8

REFERENCE		PREPARED BY	APPROVED BY	

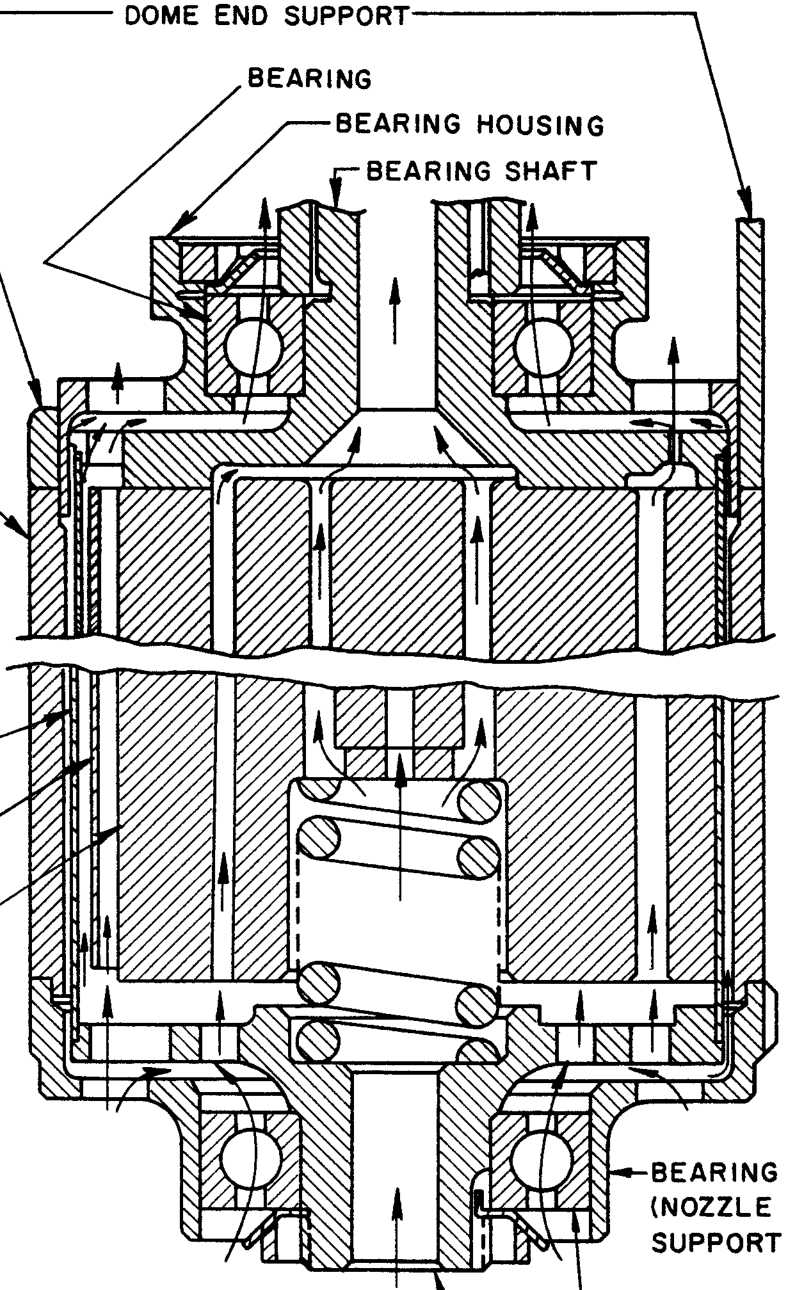


EFFECT OF TOP CLEARANCE ON LOSS COEFFICIENT WHEN SEAL IS SEATED	CURVE NO.	FIGURE NO.
	595582	3-9

REFERENCE		PREPARED BY	APPROVED BY	



EFFECT OF FILLER STRIP GAP ON LOSS COEFFICIENT	CURVE NO	FIGURE NO
	595581	3-10



CONTROL DRUM

FLOW PATTERN

FIGURE 3-11

TABLE 3-1

LOSS COEFFICIENTS FOR ENTRANCE TO FOUR CENTRAL HOLES

Location	Loss Coefficients	Ring Clearance
0.531" diameter hole in hub of nozzle end bearing shaft	1.1	0.000" - 0.120"
Entrance to four central cylinder holes	1.8 - 1.85	0.000"
	1.75	0.040"
	1.7	0.120"
	1.6	0.200"